Lat 39.05682 Lon -120.57243

Forest Health Protection

Pacific Southwest Region
Northeastern California Shared Service Area

Date: November 27, 2017
File Code: 3420

To: District Ranger, American River Ranger District, Tahoe National Forest

Subject: Evaluation of a fire-injured giant sequoia and general stand conditions within the Big Trees grove (FHP Report NE17-07)

At the request of Kelly Pavlica, Silviculturist, American River Ranger District, Tahoe National Forest, Bill Woodruff, Plant Pathologist and Danny Cluck, Entomologist, conducted a field evaluation on August 9, 2017 to determine the extent of fire injury and potential survivability of a giant sequoia (*Sequoiadendron giganteum*) sapling within the Big Trees grove. Stand conditions within and adjacent to the grove were also evaluated with a focus on white fir stand density and the associated impacts of Heterobasidion root disease (*Heterobasidion occidentale*). Kelly Pavlica and Brian Crawford, Assistant Fuels Officer, accompanied us in the field.

Key findings:

- The fire-injured giant sequoia sapling sustained severe crown scorch and has a high probability of mortality.
- It is likely that the fire-injured giant sequoia sapling was infected with *H. occidentale* through root contact with nearby infected white fir stumps, which may be a potential factor in whether or not this tree survives.
- Overstocking is putting stands around Big Trees grove at risk to high levels of bark beetle-caused tree mortality during periods of drought.
- Several native forest insects and diseases are contributing to tree mortality including bark beetles, dwarf mistletoe and root disease.
- Mortality was highest for white fir, followed by ponderosa and sugar pine.
- The abundance of root diseased white fir is creating a hazard tree problem for this recreation area and has the potential to negatively impact the health of giant sequoia trees (via root to root contact with infected white fir)
- Thinning and prescribed fire are recommended to reduce white fir stocking levels, reduce surface and ladder fuels and provide a more favorable environment for giant sequoia regeneration. Specific recommendations are provided in this evaluation.

Danny Cluck
Forest Entomologist
530-252-6431
dcluck@fs.fed.us

Bill Woodruff
Plant Pathologist
530-252-6880
wwoodruff@fs.fed.us

Description of the project area

The Big Trees grove is located 13 miles east of Foresthill, CA at an elevation of 5300 feet (39.056821N and 120.572427W). Annual precipitation is approximately 60 inches. The forest type is Sierra Nevada mixed conifer with ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Psuedotsuga menziesii*), sugar pine (*Pinus lambertiana*), incense cedar (*Calocedrus decurrens*), white fir (*Abies concolor*) and giant sequoia. The untreated portions of the stand are overly dense with scattered large old growth, high numbers of younger sawlog sized trees (10 – 20" dbh) and an abundance of small diameter (< 10" dbh) shade tolerant species (Figure 1). Treated portions of the stand had small diameter (<6" dbh) trees removed (Figure 2). Giant sequoia, ponderosa pine, sugar pine, incense cedar and Douglas-fir make up most of the older aged stand component in the overstory while the mid-story consists mostly of white fir. White fir, incense cedar and Douglas-fir make up most of the understory.

Figure 1. Dense untreated mixed conifer stand next to the Big Trees grove.

Figure 2. Dense treated (hand thinning/prescribed fire) mixed conifer stand next to the Big Trees grove.

Management objectives

Long-term management objectives for this area are to reduce stand density, reintroduce fire, reduce surface and ladder fuels and create favorable conditions for natural regeneration of giant sequoia. Reductions in stand density are limited by the need for maintaining sufficient canopy cover for California spotted owl habitat.

Observations

Fire-injured giant sequoia: The fire-injured giant sequoia sapling appeared to have minimal basal injury but 100% crown scorching. The crown scorching was most likely from heat produced by nearby shrubs and surface fuels burned during the recent prescribed fire. A few epicormic sprouts were observed on the bole of the fire-injured tree revealing that it was still alive. The fire-injured giant sequoia sapling was also growing next to two old white fir (*Abies concolor*) stumps that were infected with *H. occidentale*, the fungus that causes Heterobasidion root disease (Figures 3 and 4). It was not possible to tell if the fire-injured giant sequoia was infected, or if possible infection was affecting the tree's health, but giant sequoia is a known host for this fungus.

Figure 3. *H. occidentale* infected white fir stump next to fire-injured giant sequoia sapling.

Figure 4. *H. occidentale* fruiting body (conk) found in old white fir stump.

<u>Big Tree grove stand conditions:</u> Stand density within and adjacent to the Big Trees grove is above recommended stocking levels that would increase stand resiliency to insects, diseases and drought. Recent tree mortality is also a concern for long-term fuel loading and the immediate threat of tree hazards in this recreation area. The abundance of white fir that has established in the absence of fire is a major contributor to most of the problems observed during this site visit. White fir canopy cover and white fir regeneration appears to be preventing the establishment of giant sequoia, ponderosa pine and sugar pine seedlings. White fir density is primarily responsible for the current overstocked situation that is increasing the competition for limited soil moisture during drought. The abundance of dead and dying overstory pines and firs is evidence of this condition. White fir is also heavily infected with *H. occidentale* which is contributing to white fir mortality, creating hazard trees and potentially infecting and decaying the roots of giant sequoia.

Insects and diseases found impacting the Big Trees grove:

- Evidence of fir engraver beetle (*Scolytus ventralis*) attacks was found on several older and more recently killed white fir (Figures 5 and 6).

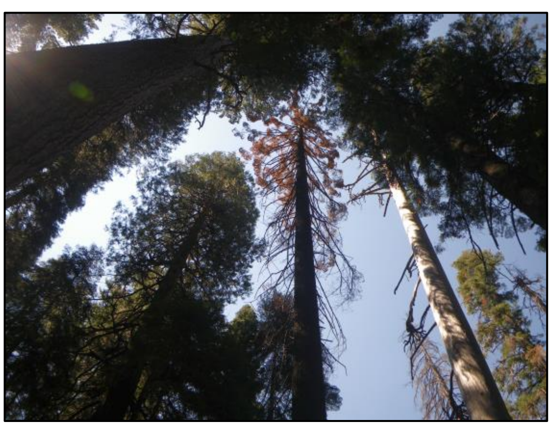

Figure 5. Bark beetle-killed white fir (center) surrounded by older bark beetle-killed trees. Also a white fir (lower right corner) with dwarf mistletoe and Cytospora canker infections.

Figure 6. Recent white fir mortality caused by fir engraver beetle attacks.

- Mountain pine beetle (*Dendroctonus ponderosae*) and western pine beetle (*Dendroctonus brevicomis*) have attacked and killed several large diameter sugar and ponderosa pines over the past 5 - 10 years (Figure 7).

- White fir dwarf mistletoe (*Arceuthobium abietinum f. sp. concoloris*) was observed on white fir.

- Branch flagging caused by *Cytospora abietis* was observed on white fir (Figure 5). Although not directly observed due to the height of symptomatic branches, this canker disease is often associated with white fir dwarf mistletoe infections.

- Fruiting bodies of *H. occidentale*, the fungus that causes Heterobasidion root disease, were found in several old white fir stumps throughout the stand.

Figure 7. Older sugar pine mortality in background associated with dense stand conditions. Trees were killed by mountain pine beetle.

Stand conditions and mortality related to recent and future climate trends

Most of the stand surrounding the Big Trees grove appears to be at or well above stocking levels that would be considered resilient to insects, disease and drought. As a result, this stand has exhibited an elevated level of tree mortality caused by bark beetles and/or root disease during the recent drought. This mortality combined with high stand density is likely to result in heavy fuel loading in many areas and a corresponding increase in potential fire behavior.

These dense stand conditions with high canopy closure also appear to have greatly reduced the amount of giant sequoia, sugar pine and ponderosa pine regeneration within the area, shifting stand composition to more shade tolerant tree species. The distribution and species composition of old growth trees within the area suggests that these stands were more open in the past, maintained by frequent low severity fire, with fewer white fir.

Predicted climate change is likely to impact trees growing in the Big Trees grove area over the next 100 years. Although no Tahoe National Forest specific climate change models are available at this time, there is a general consensus among California models that summers will be drier than they are currently. This prediction is based on the forecasted rise in mean minimum and maximum temperatures and remains consistent regardless of future levels of annual precipitation (C. Mallek and H. Safford, *A summary of current trends and probable future trends in climate and climate-driven processes in the Eldorado and Tahoe National Forests and neighboring Sierra Nevada*). The risk of bark beetle-caused tree mortality will likely increase for all conifer species under this scenario, especially drought intolerant and root diseased white fir. Improving the resilience of the Big Trees grove to future disturbance events through density, size class and species composition management will be critical to maintaining a healthy forested landscape and providing a suitable environment to maintain and enhance giant sequoia.

Discussion

The Big Trees grove and surrounding stand has become very dense with white fir with the exclusion of fire over the past 100+ years. With such a high percentage of white fir in the area, shade intolerant species tend to decline due to competition for sunlight, water and nutrients. The white fir component is creating stressful competitive growing conditions for old growth pines resulting in elevated levels of pine mortality. Regeneration of giant sequoia, sugar and ponderosa pines is practically non-existent due to the high numbers of white fir and the deep duff and litter that has accumulated over time. Heterobasidion root disease in white fir is also creating numerous hazard trees by causing mortality and decaying supporting roots of living trees.

Another aspect of high numbers of root diseased white fir is the potential to negatively affect the health and regeneration of giant sequoia. The role of Heterobasidion root disease in giant sequoia has been a topic of interest for forest managers yet little is known as to its impacts on tree health and mortality. A giant sequoia symposium in 1994 specifically addressed the issue in a General Technical Report (GTR-PSW-151, Aune 1994), the following paragraph is from that report:

"Many Basidiomycetes are responsible for the decay observed in giant sequoia trees. Heterobasidion annosum*, also called Fomes annosus, has been frequently observed in both the upper and lower stems of recent tree failures of giant sequoia trees (Piirto 1977, 1984a,b, Piirto and others 1974,). Recent research (Piirto and others 1992a,b) is shedding new light on the hypothesis put forward by Piirto (1977) and Piirto and others (1984b) involving increasing stand density levels of white fir and other associated trees species in giant sequoia groves. White fir is highly susceptible to a variety of forest diseases, particularly H. annosum. Otrosina and others (1992) and Piirto and others (1992) reported that both H. annosum isolates from white fir and giant sequoia are of the 'S' intersterility Group meaning that they are interfertile. Given the interfertility of isolates collected from giant sequoia and true fir, an increase of white fir density in the absence of natural and prescribed fire may result in the build-up of H. annosum inoculum that could affect giant sequoia trees. H. annosum may spread along with other means via root contacts from white fir to giant sequoia. In greenhouse seedling inoculation studies, isolates of H. annosum collected from true fir and isolates collected on giant sequoia were capable of causing pathogenesis on either species (Piirto and others 1992)."

*note: The scientific name *Heterobasidion annosum* was recently replaced by *Heterobasidion occidentale*, the fungal species that infects true fir, giant sequoia and spruce and *Heterobasidion irregulare*, the fungal species that infects pines, incense cedar and juniper.

The concurrent goals of maintaining high canopy cover for sensitive wildlife species and increasing resiliency to insects, disease and drought in this fire-adapted mixed conifer stand would appear to be in direct conflict. The current hand thinning of small trees (<6" dbh) and burn treatments may achieve short-term fuel reduction objectives but are not achieving a sufficient density reduction, especially of the white fir component, to lessen the risk of bark beetle and root disease-caused mortality during droughts. Excessive tree mortality during future droughts could reduce the effectiveness of fuel treatments as dead trees fall to the ground; increasing the risk of stand replacing wildfire. Excessive tree mortality may also reduce spotted owl habitat suitability due to a reduction in large tree canopy cover. Tall tree canopy cover was found to be more important than overall canopy cover in a recent study by North et al (2017).

Thoroughly treating stands by thinning and prescribed burning to reduce the risk of high severity wildfire and the risk to bark beetle-caused tree mortality is vital to maintaining and enhancing the old growth large tree attributes in the Big Trees grove. Density reduction needs to focus on the removal of white fir of all size classes, with an emphasis on lower and mid canopy trees, to achieve lower stocking levels and reduce the number of diseased trees. Treatment areas must be large enough to create a resilient space around the giant sequoias and create canopy gaps of sufficient size to facilitate natural regeneration. North et al 2017 suggests that "management strategies designed to preserve and facilitate the growth of tall trees while reducing the cover and density of understory trees may improve forest resilience to drought and wildfire while also maintaining or promoting the characteristics of owl habitat." They also state that the "reduction of sub-canopy and intermediate-size trees may reduce water competition increasing large tree resilience to beetle attack while opening up more growing space to accelerate tree growth."

In addition to giant sequoia, the Big Trees grove area contains many large diameter ponderosa and sugar pine. Thinning treatments that improve growing conditions for these three shade intolerant species, such as removing a large percentage of the white fir basal area from around these trees, would increase their health and vigor, create opportunities for their successful regeneration and improve overall resiliency to disturbance agents (insects, disease, drought and fire). Stand level thinning of competing white fir has resulted in a measured increase in annual increment growth in old growth ponderosa and Jeffrey pine on the Lassen National Forest (Hood et al 2017).

When planning thinning treatments, it should be recognized that the target stand density is an average to be applied across the landscape and some variability may be desired. Individual high value trees, such as the giant sequoias and mature pines, should benefit by having the stocking around them reduced to lower levels. Allowing for denser tree spacing and pockets of higher canopy cover may be desirable around potential wildlife trees, such as fork-topped trees. When implementing thinning projects, retaining more drought tolerant species such as ponderosa pine, sugar pine and incense cedar over white fir will increase species diversity and make the stand more resilient to disturbance agents and stresses resulting from predicted climate change. In addition, when selecting trees for removal, preference should be given to trees heavily infected with dwarf mistletoe, root disease and trees infested with bark beetles. Small group selections should be utilized to remove root disease pockets and clumps of trees with heavy dwarf mistletoe infections.

The lack of giant sequoia regeneration in the Big Trees grove is affecting the long-term survival of the grove. Creating openings and exposing mineral soil within range for seed dispersal from the existing native giant sequoia trees should result in successful natural regeneration. The Sequoia NF has demonstrated that giant sequoia regenerates well from natural seeding following disturbance. If natural regeneration does not occur, the District should consider planting giant sequoia seedlings in existing and newly-created openings after thinning and prescribed burning treatments.

The Big Trees grove should be considered a recreation area for the purposes of treating stumps to prevent new infection centers of Heterobasidion root disease. The current direction in Region 5 for recreation areas is that all conifer stumps greater than 3" in diameter must be treated with a registered borate compound (FSH R5 Supplement 3409.11-2010-1) to reduce the probability of infection by *H. occidentale* and *H. irregulare;* the causal agents of Heterobasidion root disease (formerly referred to as annosus root disease).

Considerations for Rx fire

The District has successfully conducted a recent prescribed burn in the Big Trees grove. It was noted during this site visit that large pines had duff and litter raked away from the bole prior to the prescribed burn as per prior Forest Health Protection recommendations. It appears that this treatment was very effective in reducing the amount of basal fire-injury and its continued practice is strongly encouraged.

Potential for funding thought the Western Bark Beetle Program

Forest Health Protection may be able to assist with funding, including NEPA activities, for thinning and removing green material from the Big Trees grove area. Thinning treatments that reduce stand density sufficient to lower the risk to bark beetle-caused mortality would meet the minimum requirements for Western Bark Beetle Program funding and would be supported by this evaluation. If you are interested in this competitive funding please contact me for assistance in developing and submitting a proposal.

If you have any questions regarding this report and/or need additional information please contact Danny Cluck at 530-252-6431.

/s/ Danny Cluck

Daniel R. Cluck
Forest Entomologist
NE CA Shared Services Area

/s/ Bill Woodruff

William Woodruff
Plant Pathologist
NE CA Shared Services Area

cc: Kelly Pavlica, American River RD
Brian Crawford, American River RD
Mark Brown, Tahoe NF
Forest Health Protection, Regional Office

Citations:

Aune, P.S., technical coordinator 1994. Proceedings of the symposium on Giant Sequoias: their place in the ecosystem and society; June 23-25, 1992; Visalia, CA. Gen. Tech. Rep. PSW-GTR-151. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 170 p.

Hood, S.M., Cluck, D.R., Jones, B.E., and Pinnell S. 2017 (*In press*). Radial and stand-level thinning treatments: 15-year growth response of legacy ponderosa and Jeffrey pine trees *Restoration Ecology*.

North, Malcolm P.; Kane, Jonathan T.; Kane, Van R.; Asner, Gregory P.; Berigan, William; Churchill, Derek J.; Conway, Scott; Gutiérrez, R.J.; Jeronimo, Sean; Keane, John; Koltunov, Alexander; Mark, Tina; Moskal, Monika; Munton, Thomas; Peery, Zachary; Ramirez, Carlos; Sollmann, Rahel; White, Angela; Whitmore, Sheila 2017. Cover of tall trees best predicts California spotted owl habitat. Forest Ecology and Management. 405: 166-178.

Insect and Disease Information

Fir Engraver

The fir engraver attacks red and white fir in California. Fir engraver adults and developing broods kill true firs by mining the cambium, phloem, and outer sapwood of the bole, thereby girdling the tree. Trees greater that 4” in diameter are attacked and often killed in a single season. Many trees, weakened through successive attacks, die slowly over a period of years. Others may survive attack as evidenced by old spike-topped fir and trees with individual branch mortality. Although many other species of bark beetles cannot develop successful broods without killing the tree, the fir engraver beetle is able to attack and establish broods when only a portion of the cambium area has been killed.

Evidence of Attack

Fir engravers bore entrance holes along the main stem, usually in areas that are > 4” in diameter. Reddish-brown or white boring dust may be seen along the trunk in bark crevices and in spider webs. Some pitch streamers may be indicative of fir engraver attacks; however, true firs are known to stream pitch for various reasons and there is not clear evidence that pitch streamers indicate subsequent tree mortality or successful attack. Resin canals and pockets in the cortex of the bark are part of the trees defense mechanism. Beetle galleries that contact these structures almost always fail to produce larval galleries as the adults invariably abandon the attack. Pitch tubes, often formed when bark beetles attack pine, are not produced on firs.

Adults excavate horizontal galleries that engrave the sapwood; the larval galleries extend at right angles along the grain. Attacks in the crown may girdle branches resulting in individual branch mortality or "flagging". Numerous attacks over part or the entire bole may kill the upper portion of the crown or the entire tree. A healthy tree can recover if sufficient areas of cambium remain and top-killed trees can produce new leaders. The fir engraver is frequently associated with the roundheaded fir borer and the fir flatheaded borer.

Life Stages and Development

In the summer, adults emerge and attack new host trees. The female enters the tree first followed by the male. Eggs are laid in niches on either side of the gallery. Adult beetles carry the brown staining fungi, *Trichosporium symbioticum*, into the tree that causes a yellowish-brown discoloration around the gallery. The larvae mine straight up and down, perpendicular to the egg gallery. Winter is commonly spent in the larval stage, with pupation occurring in early spring. In most locations, the fir engraver completes its life cycle in 1 year, however at higher elevations 2 years may be required.

Conditions Affecting Outbreaks

Fir engravers bore into any member of the host species on which they land but establish successful galleries only in those that have little or no resistance to attack. Populations of less aggressive species like fir engraver are likely to wax and wane in direct relationship to the stresses of their hosts. Drought conditions often result in widespread fir mortality; however, attempting to determine when outbreaks will occur is difficult. Lowered resistance of trees appears to be a contributing factor. Overstocking and the increased presence of fir on sites that were once occupied by pine species may also contribute to higher than normal levels of fir mortality. Several insect predators, parasites and woodpeckers are commonly associated with the fir engraver and may help in control of populations at endemic levels.

Western Pine Beetle

The western pine beetle, *Dendroctonus brevicomis*, has been intensivly studied and has proven to be an important factor in the ecology and management of ponderosa pine thoughout the range of the host species (Miller and Keen 1960). This insect breeds in the main bole of living ponderosa pine larger than about 8 inches DBH. Normally it breeds in trees weakened by drought, overstocking, root disease, dwarf mistletoe or fire. Adult beetles emerge and attack trees continuously from spring through fall. Depending on the latidude and elevation, there can be from one to four generations per year.

Evidence of Attack

Initial attacks are made about mid-bole and subsequent attacks fill in above and below. Pitch tubes are formed on the tree trunk around the entry holes. Successful pitch tubes are red-brown masses of resin and boring dust. Relativly few, widely scattered white pitch tubes usually indicate that the attacks were not successful and that the tree should survive. Pheremones released during a successful attack attract other conspecifics. Attracted beetles may then spill over into nearby apparently healthy trees and overwhelm the tree with sheer numbers.

Life Stages and Development

These beetles pass thorugh the egg, larval, pupal and adult stages during a life cycle that varies in length dependent primarily on temperature. Adults bore a sinuous gallery pattern in the phloem and the female lays eggs in niches along the sides of the gallery. The larvae are small white grubs that first feed in the phloem then mine into the middle bark where they complete most of their development. Bluestain fungi inoculates the tree during successful attacks, blocking trachids and vessicles which contribute to the rapid tree mortality associated with bark beetle attacks.

Conditions affecting Outbreaks

Outbreaks of western pine beetle have been observed, and surveys made, in pine regions of the Westsince 1899 (Hopkins 1899; cited in Miller and Keen 1960). An insect survey completed in 1917 in northern California indicated that over 25 million board feet of pine timber had been killed by bark beetles.Information from surveys conducted in the 1930's indicated enormous losses attributed to the western pine beetle around that time. During the 1930's outbreak, most of the mortality occurred in stands of mature or overmature trees of poor vigor (Miller and Keen 1960). Group kills do not typically continue to increase in size though successive beetle generation as is typical with Mountain Pine Beetle and Jeffreay Pine Beetle. Rather, observations indicate that emerging beetles tend to leave the group kill area to initiate new attacks elsewhere.

The availability of suitable host material is a key condition influencing western pine beetle outbreaks. In northeastern California, drought stress may be the key condition influencing western pine beetle outbreaks. When healthy trees undergo a sudden and sever moisture stress populations of western pine beetle are likely to increase. Healthy trees ordinarily produce abundant resin, which pitch out attacking beetles, but when deprived of moisture, stressed trees cannot produce sufficient resin to resist the attack. Any condition that results in excessive demand for moisture, such as inter-tree completion, competing vegetation, or protracted drought periods; or any condition that reduces the ability of the roots to supply water to the tree, such as mechanical damage, root disease or soil compaction, can cause moisture stress and increase susceptibility to attack by the western pine beetle. Woodpeckers, predacious beetles, and low temperatures act as natural control agents when beetle populations are low (endemic populations).

Mountain pine beetle

The mountain pine beetle, *Dendroctonus ponderosae*, attacks the bole of ponderosa, lodgepole, sugar and western white pines larger than about 8 inches dbh. Extensive infestations have occurred in mature lodgepole pine forests. Group killing often occurs in mature forests and young overstocked stands of ponderosa, sugar and western white pines.

Evidence of Attack

The first sign of beetle-caused mortality is generally discolored foliage. The mountain pine beetle begins attacking most pine species on the lower 15 feet of the bole. Examination of infested trees usually reveals the presence of pitch tubes. Pitch tubes on successfully infested trees are pink to dark red masses of resin mixed with boring dust. Creamy, white pitch tubes indicate that the tree was able to "pitch out" the beetle and the attack was not successful. In addition to pitch tubes, successfully infested trees will have dry boring dust in the bark crevices and around the base of the tree. Attacking beetles carry the spores of blue-staining fungi which develop and spread throughout the sapwood interrupting the flow of water to the crown. The fungi also reduces the flow of pitch in the tree, thus aiding the beetles in overcoming the tree. The combined action of both beetles and fungi causes the needles to discolor and the tree to die.

Life Stages and Development

The beetle develops through four stages: egg, larva, pupa and adult. The life cycle of the mountain pine beetle varies considerably over its range. One generation per year is typical, with attacks occurring from late June through August. Two generations per year may develop in low elevation sugar pine. Females making their first attacks release aggregating pheromones. These pheromones attract males and other females until a mass attack overcomes the tree. The adults bore long, vertical, egg galleries and lay eggs in niches along the sides of the gallery. The larvae feed in mines perpendicular to the main gallery and construct small pupal cells at the end of these mines where they pupate and transform into adults.

Conditions Affecting Outbreaks

The food supply regulates populations of the beetle. In lodgepole pine, it appears that the beetles select larger trees with thick phloem, however the relationship between beetle populations and phloem thickness in other hosts has not been established. A copious pitch flow from the pines can prevent successful attack. The number of beetles, the characteristics of the tree, and the weather affect the tree's ability to produce enough resin to resist attack. Other factors affecting the abundance of the mountain pine beetle include nematodes, woodpeckers, and predaceous and parasitic insects. As stand susceptibility to the beetle increases because of age, overstocking, diseases or drought, the effectiveness of natural control decreases and pine mortality increases.

Heterobasidion Root Disease

Heterobasidion spp. is a fungus that attacks a wide variety of woody plants. All western conifer species are susceptible. Madrone (*Arbutus menziesii*), and a few brush species (*Arctostaphylos spp.* and *Artemisia tridentata*) are occasional hosts. Other hardwood species are apparently not infected. The disease has been reported on all National Forests in California, with incidence particularly high on true fir in northern California, in the eastside pine type forests, and in southern California recreation areas.

Heterobasidion root disease is one of the most important conifer diseases in Region 5. Current estimates are that the disease infests about 2 million acres of commercial forestland in California, resulting in an annual volume loss of 19 million cubic feet. Other potential impacts of the disease include: increased susceptibility of infected trees to attack by bark beetles, mortality of infected trees

presently on the site, the loss of the site for future production, and depletion of vegetative cover and increased probability of tree failure and hazard in recreation areas.

During periods favorable to the fungus, fruiting bodies (conks) form in decayed stumps, under the bark of dead trees, or under the duff at the root collar. New infection centers are initiated when airborne spores produced by the conks land and grow on freshly cut stump surfaces. Infection in true fir may also occur through fire and mechanical wounds, or occasionally, through roots of stumps in the absence of surface colonization. From the infected stump surface, the fungus grows down into the roots and then spreads via root-to-root contact to adjacent live trees, resulting in the formation of large disease centers. These infection centers may continue to enlarge until they reach barriers, such as openings in the stand or groups of resistant plants. In pines, the fungus grows through root cambial tissue to the root crown where it girdles and kills the tree. In true fir and other non-resinous species, the fungus sometimes kills trees, but more frequently is confined to the heartwood and inner sapwood of the larger roots. It then eventually extends into the heartwood of the lower trunk and causes chronic decay and growth loss.

Heterobasidion root disease in western North America is caused by two species: *Heterobasidion occidentale* (also called the 'S' type) and *H. irregulare* (also called the 'P' type). These two species of *Heterobasidion* have major differences in host specificity. *H. irregulare* (‘P’ type) is pathogenic on ponderosa pine, Jeffrey pine, sugar pine, Coulter pine, incense cedar, western juniper, pinyon, and manzanita. *H. occidentale* (‘S’ type) is pathogenic on true fir, spruce and giant sequoia. This host specificity is not apparent in isolates from stumps; with *H. occidentale* being recovered from both pine and true fir stumps. These data suggest that infection of host trees is specific, but saprophytic colonization of stumps is not. The fungus may survive in infected roots or stumps for many years. Young conifers established near these stumps often die shortly after their roots contact infected roots in the soil.

Dwarf mistletoe

Dwarf mistletoes (*Arceuthobium* spp.) are parasitic, flowering plants that can only survive on living conifers in the Pinaceae. They obtain most of their nutrients and all of their water and minerals from their hosts.

Dwarf mistletoes spread by means of seed. In the fall the fruit ripen and fall from the aerial shoots. The seeds are forcibly discharged. The seed is covered with a sticky substance and adheres to whatever it contacts. When a seed lands in a host tree crown, it usually sticks to a needle or twig, where it remains throughout the winter. The following spring the seed germinates and penetrates the twig at the base of the needle. For the next 2-4 years, the parasite grows within the host tissues, developing a root-like system within the inner bark and outer sapwood, and causing the twig or branch to swell. Aerial shoots then develop and bear seed in another 2-4 years.

Dispersal of dwarf mistletoe seeds is limited to the distance the seeds travel after being discharged. From overstory to understory, this is usually 20 to 60 feet, but wind may carry them as far as 100 feet from the source. A rule of thumb is that the seeds can travel a horizontal distance equal to the height of the highest plant in an infected tree. There is some evidence that long distance spread of dwarf mistletoe is occassionaly vectored by birds and animals.

Vertical spread within tree crowns of most dwarf mistletoes is limited to less than one foot per year because of foliage density. Because of the thin crowns of gray pine, however, the vertical rate of spread has been measured as being greater than 2 feet per year. This rate of spread equalled or exceeded the rate of height growth of infected trees.

Dwarf mistletoes are easy to identify because they are generally exposed to view within a tree's crown. Signs of infection include the yellow-green to orange mistletoe plants, basal cups on a branch or stem where the plants were attached and detached plants on the ground beneath an infected tree. Symptoms include spindle-shaped branch swellings, witches' brooms in the lower crown, and bole swellings.